CAPE EXPEDITION—SCIENTIFIC RESULTS OF THE NEW ZEALAND
SUB-ANTARCTIC EXPEDITION, 1941–45

THE GEOLOGY OF THE SNARES ISLANDS

Part I: General Geology
by C. A. Fleming

Part II: Petrology
by J. J. Reed

Part III: Peat Samples
by W. F. Harris

NEW ZEALAND

Issued under the authority of the Hon. R. M. Algie,
Minister in Charge of Scientific and Industrial Research

CAPE EXPEDITION SERIES
Bulletin No. 13

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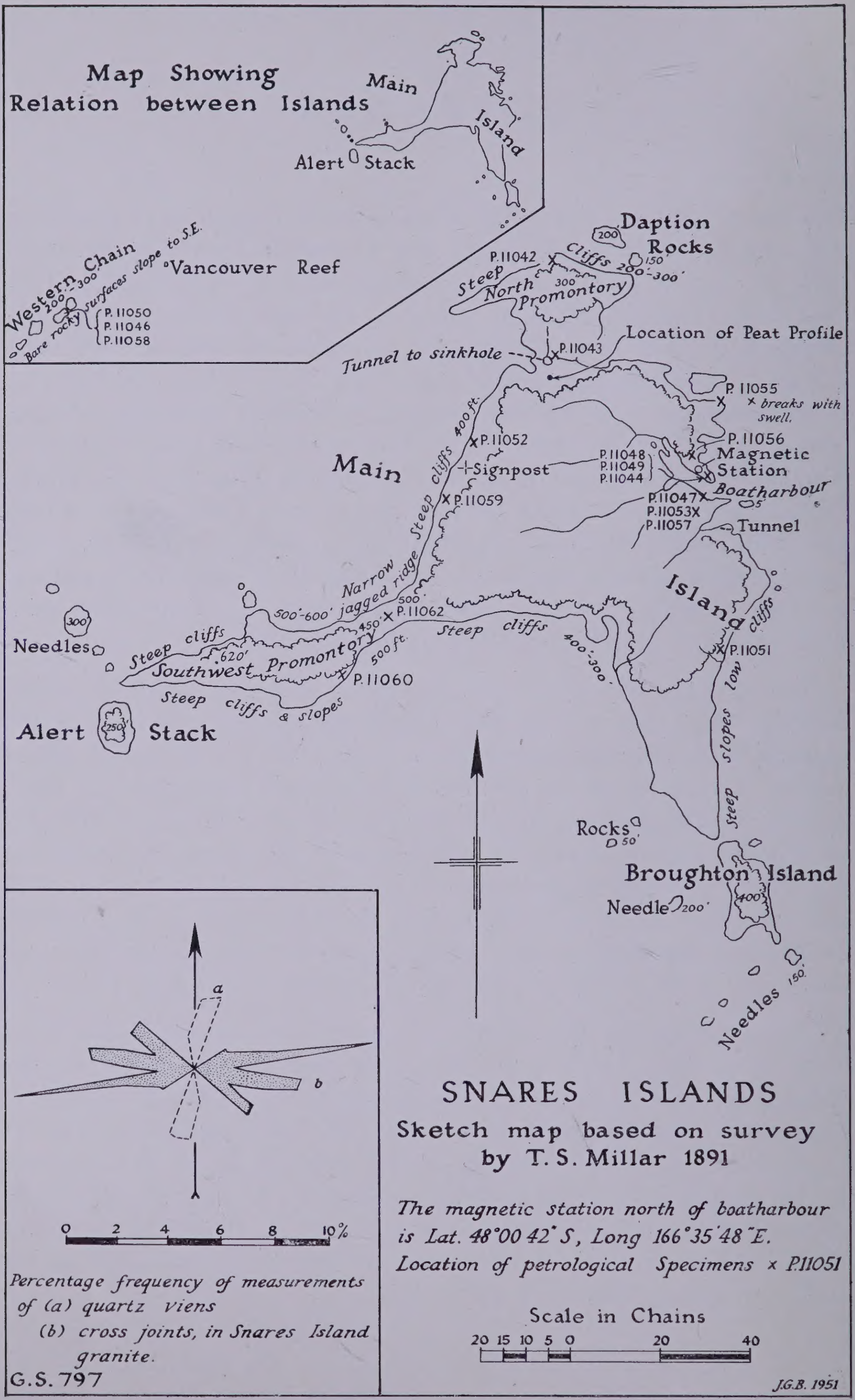
FOREWORD

This series of reports is based in the main on collections of specimens and data made at the Auckland and Campbell Islands in the years 1941–45. Early in 1941, coast-watching stations were established at Port Ross, Carnley Harbour, and Perseverance Harbour, and the personnel of from three to five men at each were relieved only once a year. Standing instructions issued by Navy Office included a recommendation that the men should, in addition to service routine, record general observations on natural phenomena. In making a selection of suitable volunteers, the Aerodromes Branch of the Works Department was able from 1942 to post at each station at least one man with some professional qualifications in geology or biology. The names of most of them are given below in the list of committee members, but the collections were enriched by the work of many others who made no claim to professional status as naturalists.

In 1944, coast-watching was abandoned and the Auckland Island stations closed, but in that year special opportunities were given for visits to the Snares and Disappointment Island. The Campbell Island station was continued for routine meteorological reporting and ionosphere research, but, except for the inclusion of a report on Aurorae as number one of this series, all results of this work are published elsewhere. Biological and geological material collected after 1945 has not generally been included, and these reports may be regarded as covering the work of the " Cape Expedition " which was the war-time code name for parties in the field between 1941 and 1945.

Arrangements for the writing of reports and for publication have been dealt with by a committee consisting of Dr. H. H. Allan (Chairman), Dr. J. Marwick, the Directors of Auckland, Dominion, Canterbury, and Otago Museums, and the following field collectors: C. A. Fleming, J. H. Sorensen, W. H. Dawbin, E. G. Turbott, and R. W. Balham. The Committee is indebted to authors who have undertaken to prepare reports, and to Mr. F. R. Callaghan, Secretary of the Department of Scientific and Industrial Research, and to his staff, for arrangements for publication.

R. A. Falla,
Hon. Secretary, Cape Expedition
Reports Committee.



Map Showing Relation between Islands
Main Island
Alert Stack
Western Chain
200-300
Bare rocky surfaces slope to S.E.
Vancouver Reef
P. 11050
P. 11046
P. 11058
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150
P. 11042
Steep Cliffs 200-300
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300
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P. 11056
Magnetic Station
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Steep cliffs
Signpost
P. 11048
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Boatharbour
5
Tunnel
P. 11059
Narrow jagged ridge
500-600
500
P. 11062
450
Island
low cliffs
P. 11051
Needles
300
Steep cliffs
620
Southwest Promontory
500 ft.
P. 11060
Steep cliffs
400-300
Steep cliffs & slopes
Alert Stack
250
Steep slopes
Rocks
50
Broughton Island
400
Needle 200
Needles
150
a
b
0 2 4 6 8 10%
Percentage frequency of measurements of (a) quartz viens (b) cross joints, in Snares Island granite.
G.S. 797
SNARES ISLANDS
Sketch map based on survey by T. S. Millar 1891
The magnetic station north of boatharbour is Lat. 48°00′42″ S, Long 166°35′48″E.
Location of petrological Specimens × P.11051
Scale in Chains
20 15 10 5 0 20 40
J.G.B. 1951

Fig. 1.

THE GEOLOGY OF SNARES ISLANDS

Part I
GENERAL GEOLOGY
By C. A. Fleming

Part II
PETROLOGY
By J. J. Reed

Part III
PEAT SAMPLES
By W. F. Harris

(The manuscripts for this Bulletin were received by the Cape Expedition Committee on 11 May 1951)

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PART I

GENERAL GEOLOGY

By C. A. Fleming, N.Z. Geological Survey

INTRODUCTION

The Snares, a group of small islands, lie in approximately 48° S. latitude, 166° 35′ E. longitude, 62 miles south-west of South-west Cape, Stewart Island. They consist of a triangular main island, four and a half miles across its base, numerous small islets, stacks, and needles, and a Western Chain of five rocky islets rising to heights of 200 to 300 ft. Accounts of the islands, their discovery, history, general appearance, vegetation, and fauna, appeared in "The Subantarctic Islands of New Zealand" (1909, edited by C. Chilton); more recently, in 1948, R. A. Falla, G. B. Murphy, and R. C. Murphy published separate general accounts, partly based on the field work of the Snares Island Expedition, November–December 1947, of which the writer was a member.

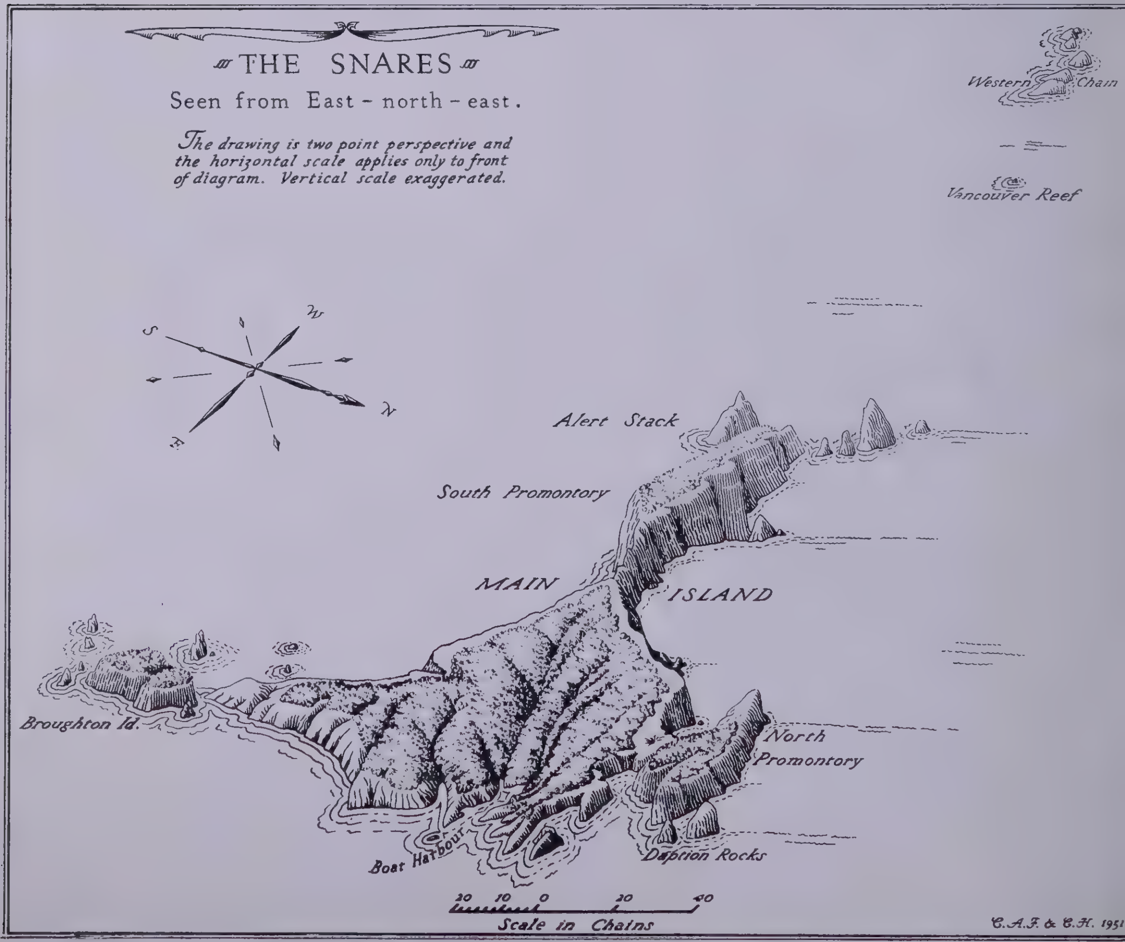
The 1947 expedition made few additions to the geological knowledge of the Snares, last reported on by Marshall (1909). The present account aims to record significant new facts and to re-assess the geological relationships of the group.

PREVIOUS GEOLOGICAL OBSERVERS

Sir James Hector (1870) quoted extracts from H. Armstrong's (1868) account of the Snares and reported that thirty-five rock specimens obtained on the group consisted of varieties of basalt, claystone porphyry, tuffaceous clay, chert, and jasper. Hector compared the series with the rocks of Dunedin peninsula, and concluded that the islands were formed by Miocene volcanism. The specimens Hector examined were certainly wrongly labelled. Basalts have now been discovered as surface pebbles, but it is unlikely that a random collection would fail to include the granite of which the islands are chiefly composed.

Twenty-five years later, Hector himself visited the islands, as the guest of Lord Glasgow, and reported (1896) that the only rock observed, at the boat harbour, was a "singular form of red granite (?), the only rock in New Zealand to which it bears a resemblance being the red granite at the entrance to Chalky inlet ". The granite formed naked domes on the surface, separated by " profound hollows " filled with " peaty matter and bird guano to a great depth as proved by the excavations for a lighthouse site some years ago ". The excavations were made in 1890 on behalf of the Marine Department near the highest part of the main island. Hector noted that the west-coast cliffs " display a stratified and columnar appearance, which suggests a doubt as to the granitic structure of the land as a whole ". During the expedition of the Philosophical Institute of Canterbury to the Subantarctic Islands of New Zealand in November 1907, Dr. P. Marshall spent part of a day traversing the greater portion of the main island in search of specimens, finding only granite with gneissic structure which was judged (Marshall, 1909, p. 704) not fundamentally different from many of the granites of Stewart Island and New Zealand. The columnar structure noted by Hector was found to be due to jointing in the granite. Marshall concluded that the Snares are " part of the

Fig. 2—Block diagram to show physiography of the Snares Islands.



same plutonic complex of which Stewart Island and the south-west of Otago are composed ". The level surface of the island, illustrated by a photograph of the northern promontory (p. 703, incorrectly labelled " south-east point "), was interpreted as a " plain of marine erosion ", indicating " a former lower level of the land ". The boat harbour was thought to be probably a submerged stream valley.

PHYSIOGRAPHY

The general physiography of the Snares Islands is illustrated in Fig. 2. The islands owe their form to marine erosion of a larger area of land. Its precise form and extent cannot be determined, although it probably occupied part of the ridge of shallow sea-bottom between the Snares and Stewart Island indicated by the available sparse soundings.

The Summit Plateau

A former erosional surface is indicated by the flat summit plateau on parts of the main island of the Snares and the even-crested profiles of the Western Chain (Figs. 3–5). The summit plateau reaches a height of 620 ft on the South-west Promontory, and slopes north-east to about 300 ft at the north and 400 ft at the south-east extremity of the main island.

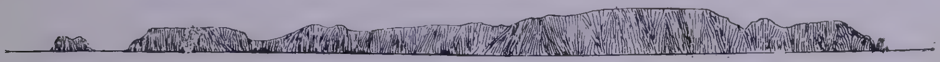


Fig. 3—Profile of main Snares Island, seen from the west, drawn from a photograph.

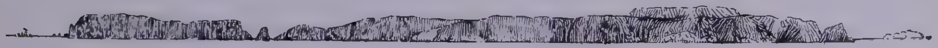


Fig. 4—Profile of main Snares Island, seen from the N.N.E., drawn from a photoghaph; Western Chain in distance on right.

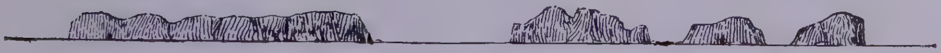


Fig. 5—Profile of Western Chain, seen from the north, drawn from a photograph.

Small streams draining the surface of the triangular main island are consequent upon the north-eastward dip of the summit plateau; they have cut shallow valleys, separated by broadly convex ridges, and have thus considerably modified the summit plateau, which is best preserved on the northern and south-western promontories (Figs. 6 and 7).

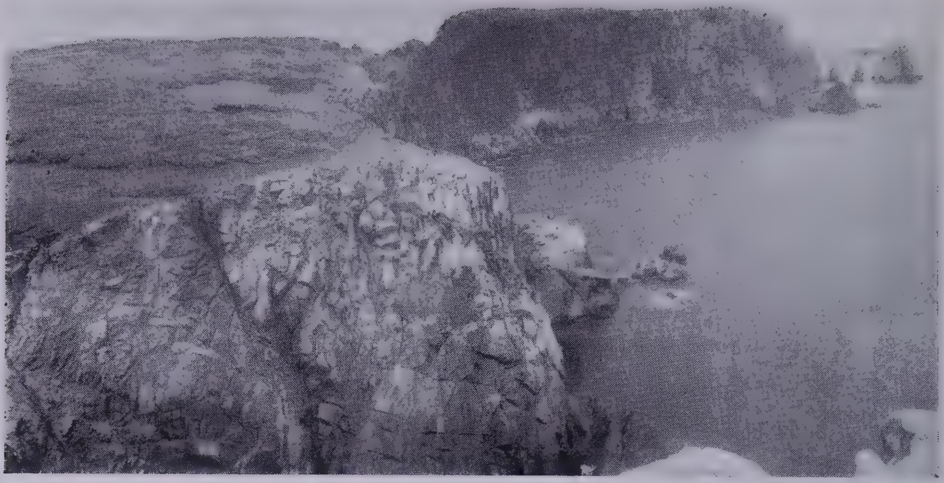


Fig. 6—View looking S.W. along the west coast of the main Snares Island towards the south-western promontory, which has a summit plateau reaching a height of 620 ft.

The south-western headland, a diamond-shaped area of summit plateau with a height of about 600 ft, surrounded by precipitous cliffs and linked to the mainland by a knife-edged ridge, is almost completely without surface relief. It supports a dense cover of *Olearia* forest on a thick soil of peaty humus, which excavations showed to be locally more than 20 ft deep (report of C. Y. Connor, representing W. Sharpe, dated 3 March 1891; Marine Department file). The thick humus cover may mask minor irregularities in the underlying rock surface. Similar thick humus was observed on the summit plateau of the northern promontory.

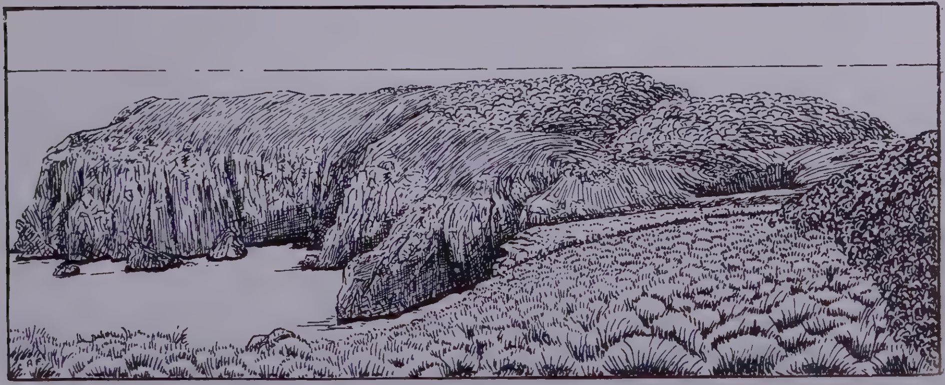
Marshall considered the level surface to mark a plain of marine erosion, cut by the sea when the land lay at a lower level. The base-level for wave attack in exposed subantarctic localities is well below low-tide level, perhaps as low as 50 fathoms, and Marshall's hypothesis implies a negative movement of sea-level of at least 650 ft.

During the 1947 expedition a careful search was made for a marine conglomerate overlying the summit plateau. Water-worn pebbles, scattered on and through the peaty humus, were found in abundance, but no bed of conglomerate was seen, and the pebbles are attributed to transport by sea-lions (see below). The origin of the summit plateau as a plain of marine erosion is not, of course, disproved by failure to locate a veneer of detrital sediment. Such sediment as existed may be locally preserved beneath the humus cover, but it is quite possible for a wave-cut platform to be swept bare by the seas that cut it. Many sea-mounts (guyots) are topped by non-depositional surfaces (Shepard, 1948, p. 303), and wave-cut platforms at shallow depths are commonly swept clean.

If the hypothesis of wave-planation is adopted, it is necessary to consider whether the subsequent elevation has been effected by diastrophic movement or by eustatic sea-level change. Henderson (1934) grouped marine terraces cut "when New Zealand was more deeply depressed than 600 ft below present sea-level" under Cotton's "Kaukau Cycle", and considered that such features had not been tilted differentially, but his conclusion has not been accepted in those parts of New Zealand where late diastrophic movements have been demonstrated. Williams (1936) recognized a prominent elevated marine terrace at 650 ft in southern Stewart Island, and high-level terraces are reported from western Southland by several geologists (see discussion of the Coastal Plateau in Benson, Bartrum, and King, 1934). Post-Tertiary diastrophic tilting has not so far been established in Stewart Island, and, if this area has been stable since the beginning of the Pleistocene, the Snares summit plateau might be considered a eustatic feature. In that case, it could be dated as Pliocene or early Pleistocene, and attributed to erosion during a pre-glacial or interglacial period of high sea-level, in accordance with the widely accepted principles of glacial eustasy. However, objections to such an interpretation justify consideration of alternative hypotheses.

The slope of the Snares summit plateau, amounting to some 200 ft a mile in a north-east (or leeward) direction, is too great (and in the wrong direction) for the initial slope of a surface cut by dominantly westerly waves, and is more in accord with a diastrophic origin. The apparent absence of features indicating Pleistocene and post-Pleistocene deformation in southernmost New Zealand (and in the Auckland Islands) suggests that the tilted summit plateau of the Snares may date from pre-Pleistocene time.

Fig. 7—Northern promontory of main Snares Island, viewed from the south, showing well-preserved summit plateau at about 300 ft and sinkhole on isthmus in foreground. Drawn from a photograph.



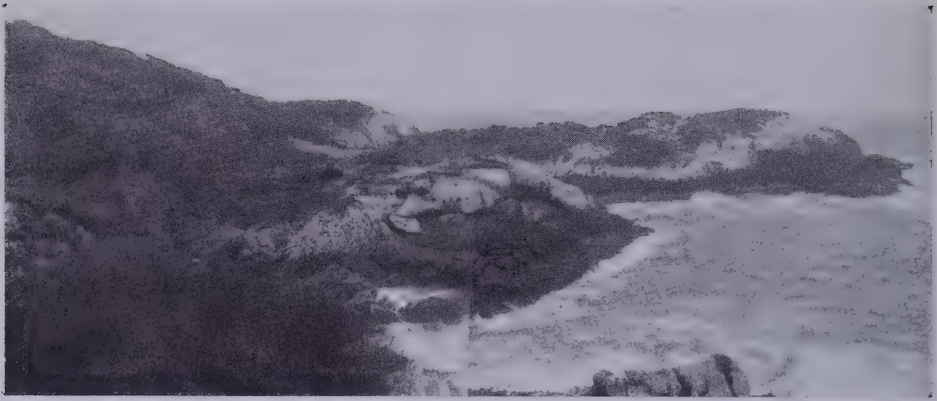


Fig. 8—Remnants of uplifted marine terrace forming headlands north of the boat harbour, main Snares Island.

No late deformed surfaces have been recognized at Stewart Island, though Williams (1936) suggested that the peaks may represent a pre-Tertiary peneplain stripped of covering beds. In southern New Zealand, two intersecting peneplains, of Cretaceous and late Tertiary age respectively, have been widely recognized by Benson (1933, 1935, 1942) and by Benson, Bartrum, and King (1934). Both peneplains truncate extensive areas of the older hard rocks of the "basement" in southern New Zealand, and both are of such wide regional extent that they may have extended over Stewart Island and the Snares.

The suggestion that the Snares summit plateau may be a remnant of one of the deformed peneplains of southern New Zealand is put forward as an alternative hypothesis to that of marine erosion during the period of Pleistocene sea-level changes. The generally deeply weathered and leached surface of the Snares granite is in accord with such an interpretation. It is clear, however, that the summit plateau at the Snares, if formed by Tertiary or Cretaceous peneplanation and warped, perhaps, in late Tertiary time, must have suffered the effects of any eustatic sea-level changes that occurred after its elevation. During glacial phases of low sea-level, the Snares suffered a climate which, judged from Willett's reconstruction of glacial climates in New Zealand (1951), must have been at least as rigorous as that of Macquarie Island at present. Under such conditions, the vegetal cover would be restricted to a discontinuous growth of tussock and herb-moor. The drowned topography of Stewart Island indicates a marine transgression to a depth of at least 180 ft (Williams, 1936) over an old landscape formed during an emergent, presumably glacial, phase. Such an emergence, at the Snares, would not greatly extend the boundaries of the land, for steep submarine slopes reach 50 fathoms within a mile of the shore.

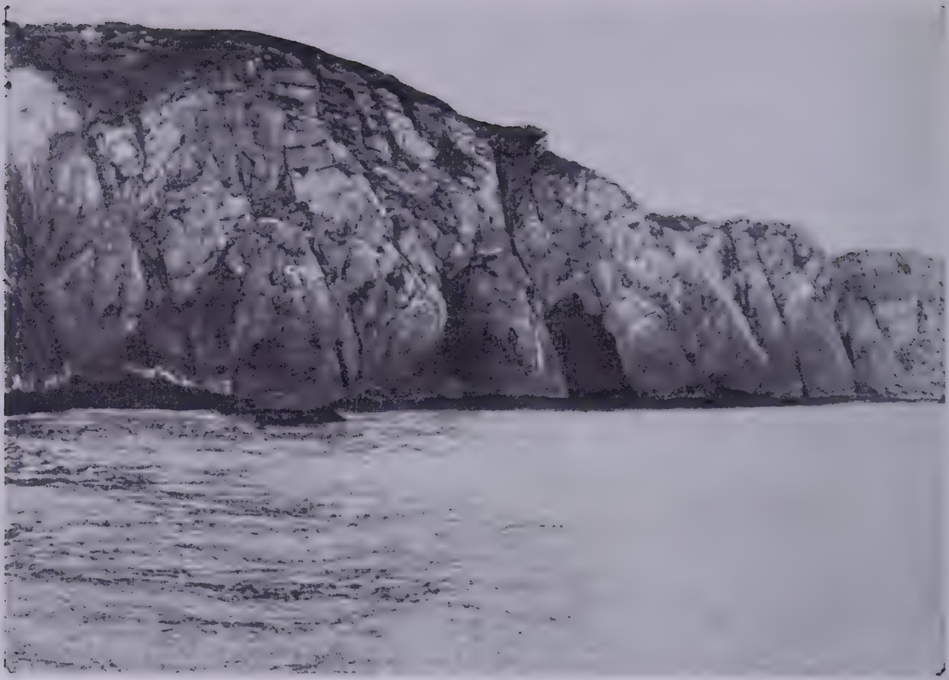
Without deposits to which a definite age can be assigned, any attempt to fix the age of the islands must be speculative. The most that may be said is that the perfect preservation of segments of the Snares summit plateau at heights up to 620 ft suggests a comparatively late, probably post-Pliocene, date for the elevation of the surface above base-level.

Marine Terraces

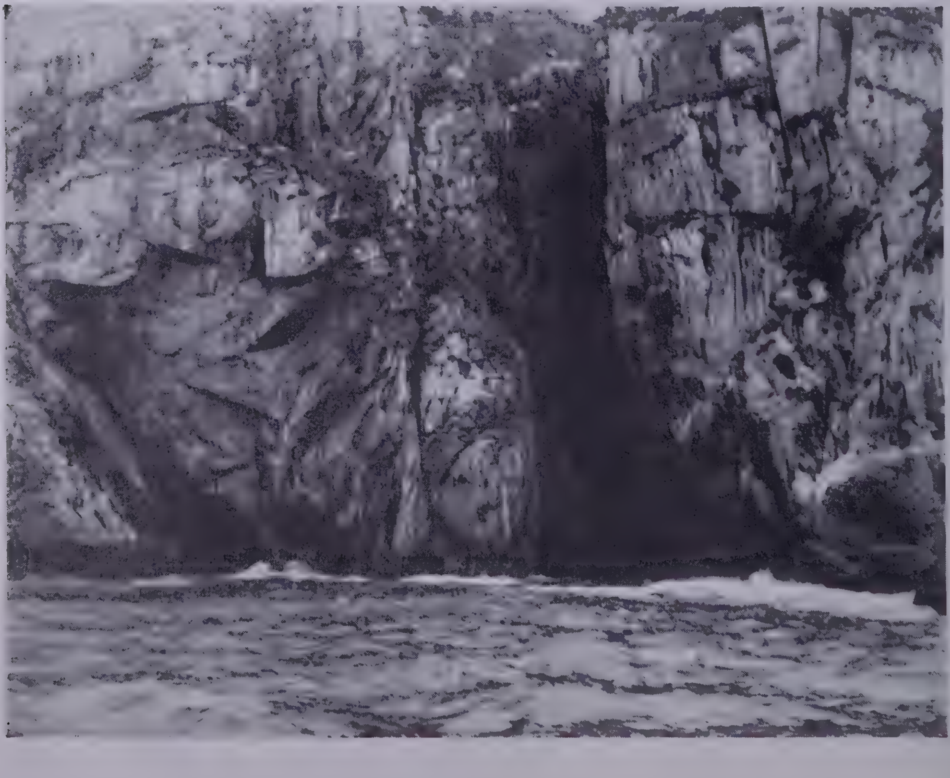
The headlands on either side of the boat harbour, on the leeward side of the main Snares Island, are terraced at a height of about 25 ft above mean sea-level (Fig. 8). Inland, remnants of this terrace are bounded by a subdued line of old sea-cliffs. Higher terraces are suggested by spur profiles, but the thick cover of peat and vegetation makes their recognition difficult. No beach conglomerate was identified.

Coastline

The coastline has the normal features of exposed islands (Marshall, 1909). The granite is seamed by almost vertical quartz and feldspar veins, of meridional trend, and fractured by joints and faults of dominantly E.N.E. direction. The two structural directions have profoundly influenced the formation of both major and minor coastal features. The long south-western promontory of the main island, its broken extension seaward to the Western Chain, and the finger-like western extension of the northern promontory are roughly parallel to the direction of jointing. The other structural direction is less perfectly reflected in the relatively straight east coast, in the passages between islets of the Western Chain, and in minor features. Measurements of the two structural lineaments in coastal exposures almost invariably show that one or other of them is parallel to the trend of the adjacent coastline (see *e.g.*, Fig. 13) or that parallel-sided gulches, caverns, embayments, and sinkholes are determined by one or both directions (Figs. 9 and 10). The somewhat curving trend of the boat harbour and its tributary gulch are parallel to the swinging strike of joints and quartz-veins respectively. The ability of powerful ocean swells to attack vertically-jointed rocks and to produce deep, narrow caverns, sinkholes, and gulches leads to a rejection of Marshall's suggestion that the boat harbour is a drowned stream valley; one of its tributary gulches enters through a cavern, roofed by rock and clearly formed by landward extension of a joint-controlled fissure. The large sinkhole in the northern isthmus (Fig. 7) is connected to both the east and west coasts by caverns, some of which are illustrated in Fig. 9. The sides of passages between outlying stacks and the main island, and between the islets of the Western Chain, are in some cases certainly, and in other cases probably, determined by the directions of jointing and veining.



Figs. 9 and 10—Sea caves controlled by joint planes, north-east coast of main Snares Island. Photos, R. A. Falla.



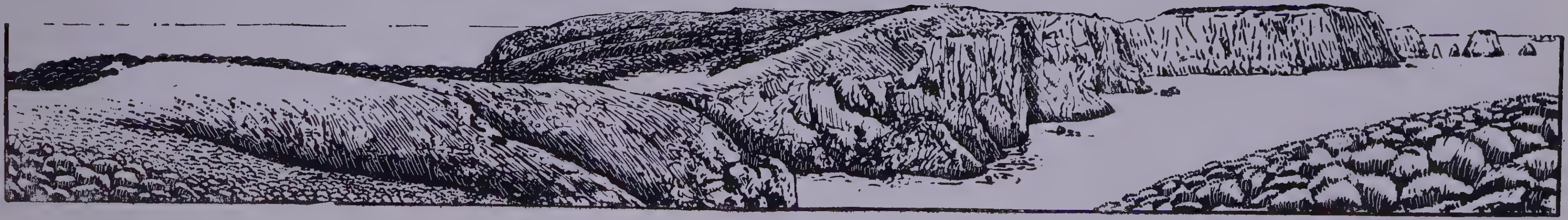


Fig. 11—Panoramic view of main Snares Island, looking south from northern promontory, across the modified summit-plateau with its north-eastward-draining streams (middle distance) towards the south-western promontory (right). The islets of the Western Chain are visible in the distance, right. Drawn from a photograph.

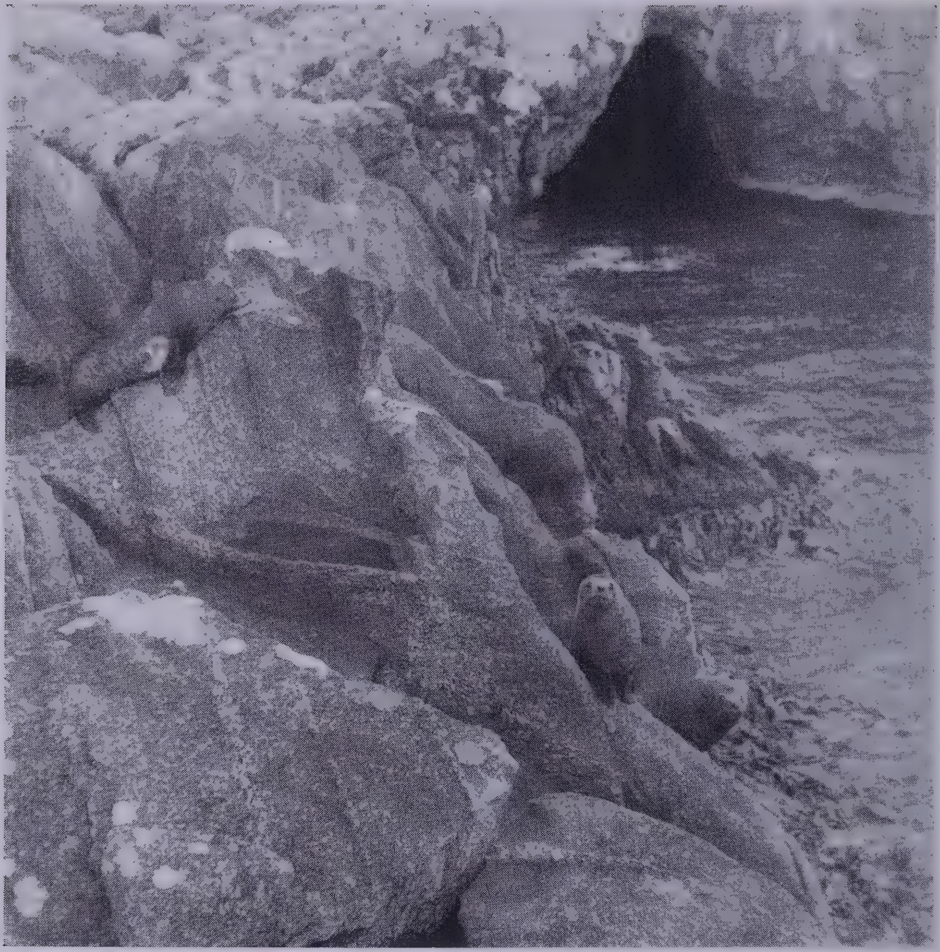


Fig. 12—Granite, penetrated by quartz veins, in coastal exposures on north-east coast of Snares Island. The cave, right background, is parallel to the quartz veins.

GEOLOGY

The Snares are composed almost entirely of somewhat gneissic granite, penetrated by quartz-feldspar and small pegmatite veins. Contact mica schist is exposed on the Western Chain. Superficial deposits comprise talus and a discontinuous cover of peaty humus, with which are associated scattered ejected sea-lion gastrolith pebbles locally concentrated as an unconsolidated lag gravel.

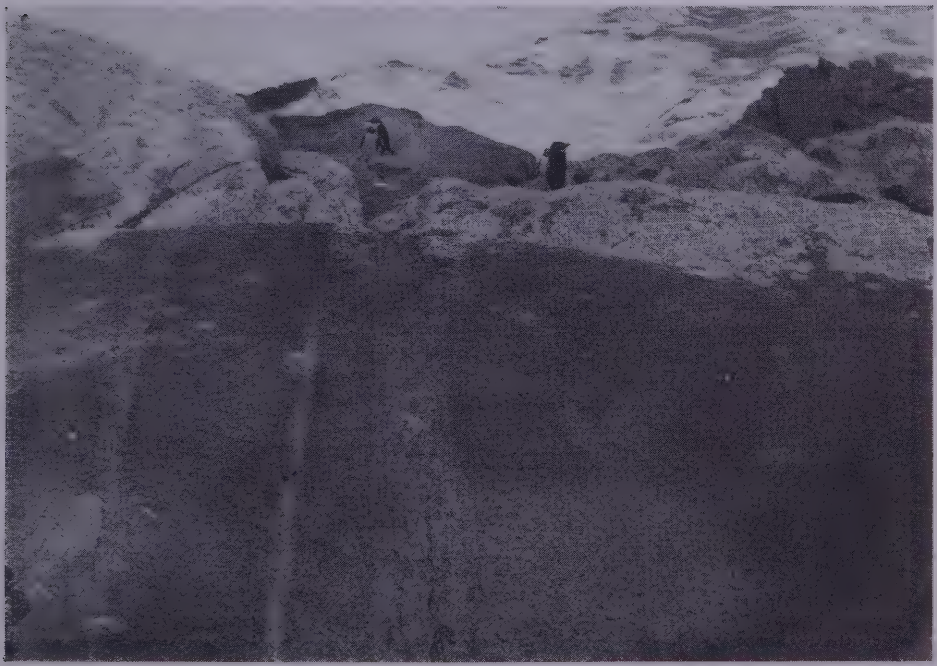
Granite

The main island, outlying islets, and stacks are composed of a fairly uniform muscovite granite, freely exposed in cliffs, shore-platforms, stream beds, and, as Hector noted, as dome-shaped masses protruding through the peat on parts of the land surface. Granite also probably forms part of the Western Chain; samples of rock from one islet of the chain include a quartz-feldspar vein.

At sea-level, where it is kept moist, the granite appears dark brown, but at higher levels, where the surface is weathered, pink tones predominate. A discontinuous growth of lichens contributes to the paleness of the rock. In clean coastal exposures, the granite appears coarsely granular owing to differential weathering of its constituent minerals (Fig. 13).

The granite is closely jointed, and coastal weathering has isolated irregular cores originally joint-bounded which give a characteristic architectural appearance to parts of the shore. Unweathered subhorizontal surfaces commonly display two sets of intersecting joints, one of which is parallel to quartz-feldspar and pegmatite veins traversing the granite, the other crossing at an angle of about 70° and dividing the rock surface into diamond-shaped segments. The primary direction (of quartz and pegmatite veins) ranges from 1° to 41°, the mean being 15°; the secondary direction from 56° to 131°, the mean being 96°. The primary direction is parallel to the slight macroscopic signs of preferred orientation in the crystals of the granite. The secondary joints are commonly fractures along which quartz veins are displaced to a minor extent (apparently up to a

Fig. 13—Pegmatite and quartz veins, trending north, north-east coast of Snares Island.



foot), but there appears to be no consistency in the direction of movement; most of them are clearly younger than the quartz veins and only a few of them are themselves occupied by quartz veins. Measured primary joints and veins are vertical or dip westward at high angles; secondary joints are vertical or dip southward. A third system of sub-horizontal joints (Fig. 12) is less conspicuous than the other two, but locally gives the appearance of stratification that Hector noted (1896); in most places, however, the secondary joints are most conspicuous (Fig. 13). Locally, the jointing appears quite irregular, but close examination generally reveals the dominance of the two vertical directions.

The granite specimens obtained during the 1947 expedition are described by J. J. Reed in Part II.

Mica Schist

Dr R. A. Falla landed on the second islet (from the north) in the Western Chain on 4 December 1947, and obtained several chips of rock lying on the surface near nests of Cape pigeons. The specimens include contact schist and fragments of quartz veins. Photographs of the rocky south-east slopes of the islet show irregularly-jointed structure in what could conceivably be schist, although no schistosity is apparent. The schist is softer than the Snares granite, and it seems unlikely that the residual stacks comprising the Western Chain are composed entirely of such unresistant material. Dr Falla considers that schist is limited to upper parts of the islet and that the shore is formed of rock similar to the Snares granite. It is reasonable to suppose that the schist constitutes part of the country rock of the granite batholith of which the Snares are a part, highly metamorphosed by contact effects, forming part of the contact aureole or, more probably, a roof-pendant. Williams (1934 a, b) has reported roof-pendants of amphibolite, calc-silicate-hornfels, and biotite-muscovite schist in the granite of southern Stewart Island, some 80 miles north of the Snares.

J. J. Reed has described the schist on pp. 29–30.

Superficial Deposits

Talus deposits of granite boulders lie at the foot of many of the sea cliffs and within the large sink-hole on the isthmus linking the northern promontory with the main island.

The surface of the island is covered by a discontinuous layer of peat, up to 20 ft thick. Aston (1909) has emphasized that the soils of New Zealand subantarctic islands differ from peat (in the restricted sense of the word) in their manner of formation, being composed chiefly of decayed higher plants (locally on relatively steep slopes and not in stagnant water) and supporting a vigorous growth of higher plants. It would be pedantic, however, to quibble at the well-established use of the term "peat", not only in New Zealand but elsewhere, as applied to the thick, waterlogged humus soils of the subantarctic islands.

Snares peat is dark reddish-brown to black, and contains many recognizable plant fragments (leaves, stems, grasses, and roots) in its surface layers. Natural sections, in concave scars, bare of vegetation and formed by wind deflation or "bog-slides", expose lower layers. At depths of more than a few feet below the original surface, the peat is dark, homogeneous, and waxy, and shows conchoidal fracturing when dry. The excavations made in 1890 for a proposed lighthouse consisted of two shafts sunk on the highest part of the island. In one, rock was not encountered at 20 ft, but the other struck crumbly granite at 18 ft. The shafts penetrated soft and spongy peat, described as "a mixture of dirt, vegetation, roots, guano, and rotten granite".

Samples of Snares peat have been described and analyses presented by Aston (1909, pp. 757 and 772–5). Fairly large particles of mica characterize deeper layers. Aston found a gradual increase from the surface downwards in the amounts of salts derived from sea-water.

Fossil pollen-grains preserved in the peat elucidate the post-Pleistocene history of vegetation and climate at the Snares. Samples collected in 1947 were submitted to W. F. Harris, Palynologist, Botany Division, Department of Scientific and Industrial Research (see Part III). The evidence of forest retreat and increasing tussock may reflect climatic deterioration since the post-glacial optimum.

Reports of guano at the Snares have led to several applications for lease of the islands since 1888. In January 1889 the ketch "Anna" brought "6 tons of guano from a local deposit in a cave on the east coast of the Snares. The material consisted of seal-dung, hair, and rotten-rock" (Marine Department file). The size of the deposit was unknown. During the 1914–18 war, interest was revived. Three samples of "guano" (probably peat) were analysed by B. C. Aston and found to contain 0·14 to 0·27 per cent of P_2O_5 when air-dried, and 1·9 to 5·5 per cent when ignited (Department of Agriculture file). A more recent analysis of Snares Island peat collected in December 1947 by F. Newcombe, Department of Internal Affairs, was made by the Soil Bureau. The analyst's report states that the peat is very acid pH = 3·8), carbon content normal, but nitrogen above average, probably on account of bird droppings. The percentage of exchangeable lime (22·8) and potash (1·40) is also high, for the same reason. Loss on ignition was 95·6 per cent, leaving 4·04 per cent mineral soil. Thus the Snares Island peat is of ordinary composition except for the additions due to bird droppings (report on lab. sample No. 4738, New Zealand Soil Bureau, 26 April 1948).

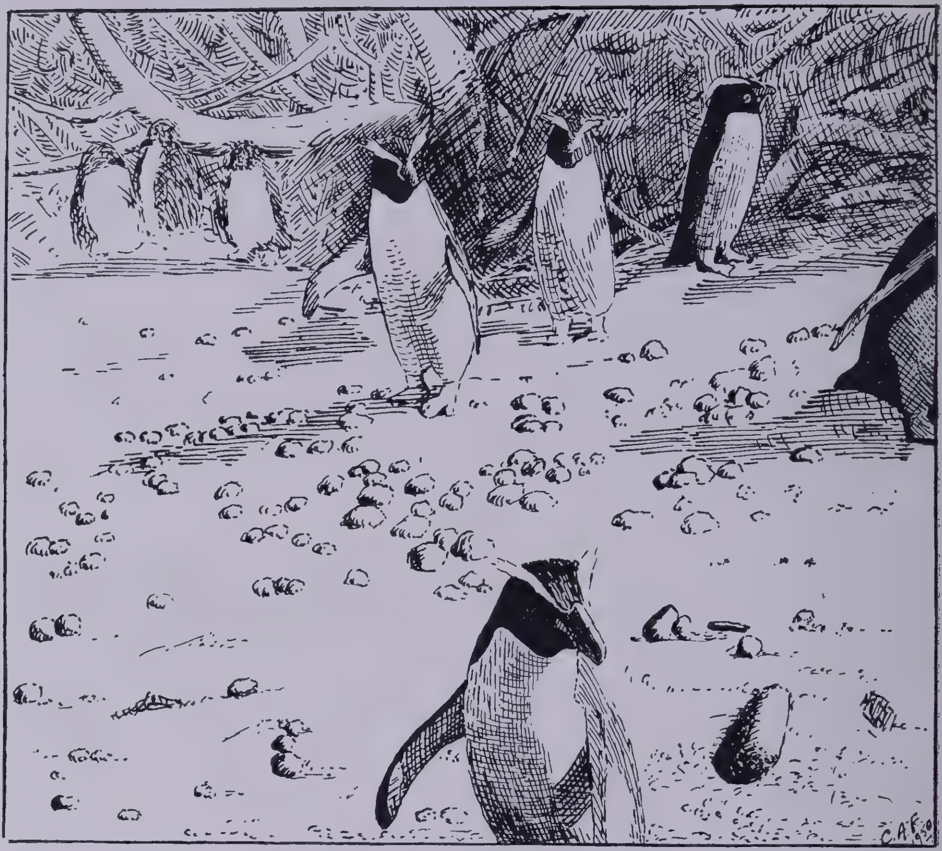


Fig. 14—Sea-lion gastrolith pebbles, forming a diffuse lag gravel on the surface of rock exposed in a penguin colony, Snares Island. Drawn from a photograph.

Sea-lion Gastroliths

Scattered, well-rounded, water-worn pebbles lie on the surface of the peat on many parts of the main Snares Island, but are nowhere aggregated in a definite deposit. Rare rounded pebbles are embedded in the peat at depths of several feet from the surface and at unknown heights (exceeding 3 ft) above the underlying basement of granite. Long-established penguin colonies, originally situated on peat, now occupy an exposed rock surface, for the protecting vegetation has been killed, and constant tramping has helped rain-wash to scour away the peat. In such places a lag-gravel of water-worn pebbles remains on the rock surface, between penguin nests (Fig. 14).

Water-worn pebbles were found on the east coast and on the northern isthmus, at heights up to about 250 ft, but were not recorded from the higher parts of the island at greater distances from the east-coast landing places.

The pebbles range from 1 in. to about 4 in. long and are round or ovoid. Most are composed of Snares granite, but a small proportion are of dark, heavy, fine-grained basalt. The nearest known basaltic rocks are at the Auckland Islands, some 130 miles to the south. The distribution of the pebbles, on the surface or within a layer of Recent peat, prohibits any suggestion that they were derived from basalts now submerged, or that they were transported by shore drift or icebergs during a Pleistocene stage of different sea-level or climate.

The Snares Islands support a large population of fur seals (*Arctocephalus doriferus forsteri* (Lesson)), which are confined to the coastal rocks, never entering the scrub and tussock of the land. A smaller population of Hooker's sea-lion (*Zalophus hookeri* (Gray)) consists almost entirely of sub-mature males, which habitually visit the coastal scrub and tussock at heights of several hundred feet above the shore. They may occasionally breed, but have not so far been recorded doing so. The chief breeding places of the sea-lion in the New Zealand area are at the Auckland Islands, and the animals that frequent the Snares, Campbell, and Antipodes Islands, the coasts of southern New Zealand, and Stewart Island are chiefly immature, and are classified as a non-breeding overflow from the Auckland Islands population. It is not known how regularly nor how rapidly sea-lions make the passage between the Auckland Islands and the Snares, but it may be safely inferred that they do so.

Sea-lions habitually take up and swallow pebbles, probably, as suggested by Turner (1887), to assist the trituration of food in the stomach; alternative suggestions have been listed by Hamilton (1934) and Emery (1941). Probably they obtain the pebbles on the shallow sea-bottom while diving and groping for their animal food: they have not been observed to take them up on land. After a period of feeding at sea, the animals come to land and lumber up the slopes into coastal scrub and forest, sometimes to a height of more than 600 ft (Auckland Islands). On land, sea-lions lie sleeping and drowsing for several days, and during this interval the gastrolith pebbles are ejected, commonly with undigestible food remains (cephalopod, gastropod, crustacean, fish). The ejection of gastroliths is accompanied by regurgitatory movements, belching, and grunts, which culminate in the projection of a group of pebbles, several pounds in total weight. Sometimes the pebbles are deposited as a compact group, but violent shaking of the head during the process may splatter them over an area of several square yards, where they lie on the surface of the peat and are pressed into it by the subsequent movement of the animals across them.

The above account of the behaviour of Hooker's sea-lion is based on personal observation at the Auckland and Snares Islands. Stones and gravel are commonly recorded from the stomachs of other Pinnipedia (Turner, 1887; Wilson, 1907; Hamilton, 1934; Bertram, 1940, other references quoted by Emery, 1941). The ejection of gastroliths on land has seldom been described. Indeed, Hamilton stated that he had never observed the Falkland sea-lion throwing up its stomach pebbles.

The discovery of basalt "erratics" among superficial pebbles at the Snares, and their manner of occurrence, drew the writer's attention to the sea-lion's habit of regurgitating gastroliths. In subsequent examinations of freshly ejected pebbles, none were seen with a length greater than about 2½ in., and no basalt pebbles were found. Emery (1941) quotes a record of "single rocks weighing as much as 5 lb." from the stomach of an unspecified seal, and Hamilton measured one stone 94 mm. (3¾ in.) long from the stomach of the Falkland sea-lion (*Zalophus byronia*). It seems that the largest rounded pebbles at the Snares could well have been ejected by a sea-lion.

The ability of marine mammals to transport pebbles has recently been emphasized by K. O. Emery (1941). Emery concluded that sea mammals "cannot be quantitatively important as geological agents" but that "infrequent pebbles in fine-grained sediments may sometimes be due to the activity of sea mammals as well as to other forms of rafting". He did not envisage the long-distance transport of "erratics", far from their source, their ejection on land, and their accumulation locally in large numbers. If correctly interpreted, the superficial pebbles at the Snares show that some marine mammals may locally be important geological agents (Fleming, 1951).

Isolated granite pebbles deeply buried in the Snares Island peat recall the "chuckie-stones" in Cretaceous coal-seams at Greymouth, New Zealand (Gage, 1949). However, the lack of known large Cretaceous land animals in New Zealand favours Gage's attribution of "chuckie-stones" to root-rafting.

STRUCTURE AND GEOLOGICAL RELATIONSHIPS

Marshall considered that the Snares granite forms part of the same plutonic complex as Stewart Island and the south-west of Otago (western Southland). Discovery of an apparent roof-pendant of schist at the Snares strengthens the resemblance to southern Stewart Island. The late Tertiary volcanoes of the Auckland Islands (Speight and Finlayson, 1909) overlie a basement of older rocks which include granite, high-grade mica schist (apparently the result of contact metamorphism), and gneiss, the latter two constituents occurring in a Tertiary conglomerate.

In the New Zealand area, granites are limited (with one exception) to a belt of Paleozoic and perhaps older rocks which extends south on the west coast of the South Island from north-west Nelson through Westland to western Southland (summary by Reed, 1948). Broken by Foveaux Strait, the granite belt continues in Stewart Island, and is probably thence continuous beneath the waters of the southern ocean to the Snares and Auckland Islands. To the east of the granite belt, as recently indicated by Wellman (1948), the oldest known rocks exposed are a sequence of upper Paleozoic to Jurassic geosynclinal sediments, the lower members regionally metamorphosed to schist. The exceptional occurrence of granite referred to is at the Bounty Islands, far to the east of the New Zealand mainland, and its structural relationships are quite unknown.

In western Southland, some of the sediments with granite intrusions contain lower Ordovician fossils, and unfossiliferous metamorphosed sediments are also classed as Ordovician (Benson, 1933). Granites intruding into the Ordovician sediments have been mapped as " Late Paleozoic? ". The probable age of the Snares mica schist is thus early Paleozoic, and the Snares granite is possibly late Paleozoic.

The granite-invaded lower Paleozoic sediments of the western South Island may be regarded as forming part of the geanticline bordering the late Paleozoic-Jurassic geosyncline to the east. The axis of the geosynclinal sediments (Macpherson's Wanaka Series structure trend, 1946) swings eastward across Otago to the coast near Dunedin, and its submarine course beyond the limits of the South Island is not known. Possibly it trends towards the Chatham Islands, which have a basement of schist resembling Otago schist (Allan, 1925). Macpherson (1946) has drawn later folds parallel to the older axes within the limits of New Zealand. Possibly, therefore, the late Paleozoic-Jurassic geosyncline trends south, parallel to the relicts of its western borderland, towards Campbell Island, where low-rank regionally metamorphosed schist has recently been re-described by Oliver (1950). Many earth movements have occurred since the deposition of Jurassic sediments east of a rising borderland of older Paleozoic rocks, and the trend lines of later deformation have not always paralleled older structures. The trend of the submarine ridge from south-eastern Stewart Island towards the Snares and Auckland Islands is doubtless a Tertiary feature, and should not be given too much importance in determining older tectonic directions, although it is possibly superposed on an older trend.

Benson (1933, p. 421) described the Ordovician sediments of Preservation and Chalky Inlets as folded and intruded " under the compulsion of thrust from the west ", the axes of folding trending somewhat west of north; the deposition of quartz in fractures was the last event of this phase. Later, long after the geosynclinal stage and the emplacement of batholiths, low-angle thrusting from the east developed. Of five systems of faults, fractures, and joint planes recognized, a series trending nearly east and west (generally north of east) is the most clearly marked. In southern Stewart Island (Williams, 1934b) the dominant tectonic trends, marked by the directions of elongate roof-pendants, are about 10° to 20° and 70°. The primary joint direction in the Snares granite, about 15°, is also the direction of quartz veins and small pegmatite veins injected in the late stages of orogeny and invasion, along the direction of incipient gneissic structure; it is judged to be the probable trend of folding during the emplacement of the batholith. No structure has been observed in the Auckland Islands granite.

The evidence is not opposed to the hypothesis that the sinuous line joining the granites exposed in western Southland, southern Stewart Island, and the Snares and Auckland Islands is parallel to the chief direction of folding during the post-Ordovician (probably post-Devonian) period of orogeny in which they were emplaced, but such a statement of relationship may be oversimplified (Fig. 15).

The secondary joint-direction at the Snares, roughly east, but generally north of east, is the same as the most clearly marked fracture direction in the Preservation Inlet region and almost the same as the 70° direction of Stewart Island roof-pendants.

At the Snares, movement along the secondary fractures is undoubtedly of later date than the primary direction, but there is no evidence to connect such fractures with either the early Cretaceous or late Tertiary orogenies that New Zealand has suffered.

It is reasonable to suppose that the Snares shared in the complex movements that affected every part of New Zealand during later geologic time. From the known Tertiary history of adjacent areas it can be inferred that the Snares suffered several phases of marine transgression, sedimentation, and erosion, in common with most of the unstable New Zealand region. In an area where all major features of surface relief reflect tectonic patterns of Tertiary or post-Tertiary age, it is also reasonable to infer that a submarine ridge, such as that between Stewart Island and the Snares, marks the axis of a late Tertiary fold. Possibly the emergence of the Snares summit plateau to form the present islands resulted from a local upward doming of the crest of that fold.

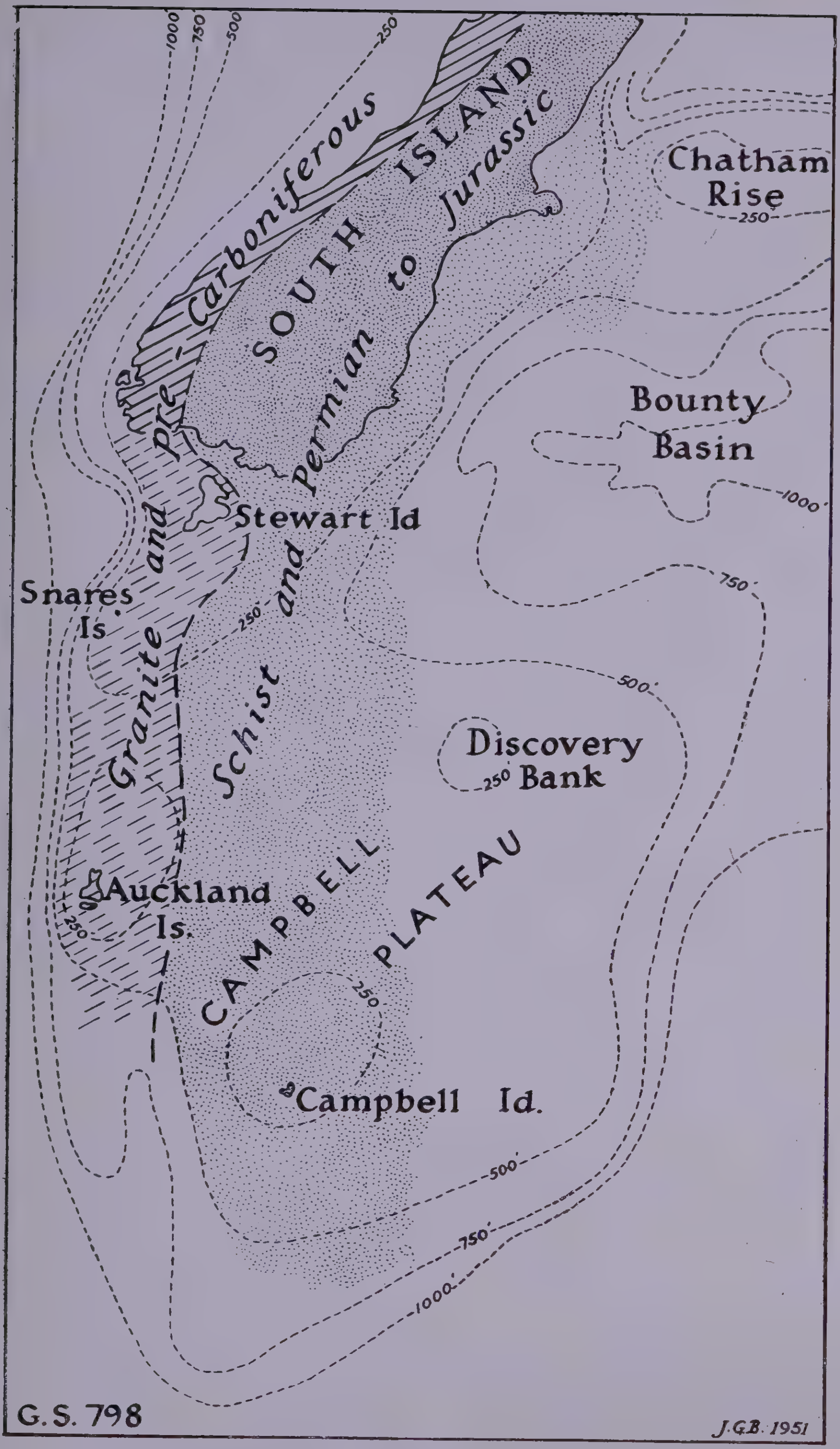


Fig. 15—Map of southern New Zealand, and outlying islands, showing generalized distribution of older rocks. Older Paleozoic sediments with granite intrusions hachured, younger Paleozoic to Jurassic sediments and schist stippled. Isobaths drawn from Admiralty Chart No. 788 and from additional data supplied by courtesy of N.Z. Naval Board.

PART II

PETROLOGY

By J. J. Reed, N.Z. Geological Survey

INTRODUCTION

Eighteen rock specimens in the N.Z. Geological Survey (see Fig. 1), collected during November and December 1947 by the Snares Expedition, have been examined. The rocks can be grouped into:

(*a*) Granite and associated pegmatite and quartz veins:
(*b*) Mica schist:
(*c*) Sea-lion gastroliths.

GRANITE AND ASSOCIATED PEGMATITE AND QUARTZ VEINS

As noted by Hector (1896), Marshall (1909), and Fleming (Part I), the Snares are composed almost entirely of granite, of which ten specimens were collected. Megascopically, the granite samples are equigranular and medium grained, and consist of quartz, feldspar, and conspicuous muscovite flakes. The rock is greyish white when fresh (11043), but the majority of the specimens are weathered pinkish or brownish. In some specimens (11047, 51) a gneissic structure has resulted from the sub-parallel arrangement of the mica plates.

In thin section the specimens are all very similar, the texture being hypidiomorphic granular, and the main constituents are quartz, plagioclase, orthoclase, and muscovite mica. The quartz and feldspar grains range from 0·2 to 1·5 mm. (average size, 0·9 mm.) and the mica flakes measure up to 5 mm. in length. All the quartz and most of the feldspar show pronounced undulose extinction between crossed nicols. Clear anhedral grains of quartz constitute 30 to 40 per cent of the rocks. Plagioclase feldspar, which forms 20 to 40 per cent, is of two types: (*a*) untwinned albite (An_5 to An_{10}) and (*b*) oligoclase An_{15} to An_{25}) displaying fine lamellar twinning. Untwinned allotriomorphic orthoclase crystals form 6 to 20 per cent of the rock, and in a few cases these show perthitic intergrowths with albite (11047) and micrographic structure with quartz (11042). The only mica in most of the specimens is muscovite, which in one case (11043) constitutes about 15 per cent of the rock. Biotite, a minor constituent (1 per cent) in 11042, displays the following pleochroism: X — pale yellow, Y — pale brown, Z — dark brown. Absorption X > Y > Z. Accessory minerals are almandite garnet occurring in anhedral, pale pink crystals measuring 0·05 to 0·3 mm. in length (11043, 47, 49), rare zircon prisms (11043), and rare apatite (11043).

Petrographically the specimens are similar to the granite collected at the Snares by Marshall (1909, p. 704). In Table 1, a chemical analysis by F. T. Seelye of one specimen (11043) can be compared with the older incomplete analysis of Aston (1909, p. 769). The standard C.I.P.W. weight norm and the molecular norm (Barth, 1948, p. 51) are given in Table 2. As both these calculations ignore the presence of muscovite, a closer approximation can be obtained if the equivalent molecular percentages are distributed according to the modal minerals determined in thin section (Table 3). This table demonstrates one of the main features of the Snares granite (viz., the predominance of sodic plagioclase feldspar over potash feldspar).

The muscovite granite at the Snares contrasts with the biotite granites from the Auckland Islands (Speight and Finlayson, 1909, pp. 720, 726), Bounty Island (Speight and Finlayson, 1909, p. 739), Stewart Island (Williams, 1934b, pp. 323–4), Preservation and Chalky Inlet (Benson and Bartrum, 1935, pp. 135–6), and Green Islets (Park, 1926, p. 385). The chemical analyses available for these rocks are given in Table 1.

The two pegmatite samples (11048, 49) are coarser grained than the granite and contain plentiful microcline feldspar. A specimen (11050) from the main veins cutting the granite (p. 19) consists entirely of quartz.

MICA SCHIST

Small specimens of mica schist (11050, 11058) lying on the surface near nests of Cape pigeons were collected by Dr. R. A. Falla on 4 December 1947 from the second islet (from the north) in the Western Chain. The largest specimen (11050), measuring 4 by 3 by 2 cm., is dark-coloured and highly micaceous, whereas the other smaller samples 11058A and B) are lighter coloured and contain more quartz. Examination of a thin slice of 11050 indicates that its approximate composition is: quartz 35 per cent, biotite 30 per cent, muscovite 30 per cent, and apatite 5 per cent. The xenoblastic biotite and muscovite flakes, 0·1 to 1 mm. in length, display a sub-parallel arrangement and show a tendency to be separated into layers from the clear, strained, interlocking, quartz grains, the majority of which are 1 mm. in length, but small sutured granules are also present. Some quartz is interstitial between the mica flakes. The biotite is a brownish variety, the pleochroism ranging from pale yellow or brown (X) to dark reddish or olivaceous brown (Y Z). In some of the muscovite flakes ($2V = -45°$) there is biotite along the cleavage planes, and in others minute sillimanite hairs can be identified. Apatite is an abundant accessory mineral occurring in colourless euhedral crystals, some of which are enclosed by mica, particularly biotite. Minor accessory minerals are prisms of zircon and rare sagenitic rutile in quartz. The other specimens differ from 11050 in that quartz is more abundant and apatite less so, while in one sample (11058B) the biotite is greenish-brown. Sillimanite hairs and needles are well developed in the muscovite plates of 11058A.

The mica schist specimens described above are comparable with the mica schist inliers in granite described by G. J. Williams (1934b, pp. 324–9) from Stewart Island. The schists are of "contact" rather than "regional" metamorphic type.

Several of the rock chips from the Western Chain consist entirely of quartz and are presumably from narrow veins, as none are comparable with the quartzites associated with almost all the mica schist inliers on Stewart Island (Williams, 1934b, p. 329). It would be of interest, when opportunity offers, to search for the possible presence of quartzite with the mica schist on the Western Chain.

SEA-LION GASTROLITHS

Scattered, well-rounded, water-worn pebbles on the surface of the peat on many parts of Snares Island are considered by Fleming (Part I) to be sea-lion gastroliths. Many are specimens of the Snares granite, but a small proportion are of a dark, fine-grained type not known to crop out on the island. The petrology of these foreign pebbles is dealt with in this section.

Examination of the pebbles (11053, 56, 57), the largest of which is 10 cm. in length, indicates that they are basaltic rocks, very similar in general texture and composition, and differing only in grain size. In the coarsest specimen (11056), feldspar laths 1·5 mm. in length display sub-ophitic relationship to xenomorphic pyroxene crystals measuring 0·03 to 1 mm. In the fine-grained pebbles (11053A) the texture becomes intergranular with aggregates of pyroxene crystals less than 0·4 mm. between a sub-radial network of feldspar laths 0·6 mm. in length. The feldspar is basic labradorite, for which measurements with the universal stage using the methods of Nikitin (1936) and Turner (1947) gave the range as $An_{58} Ab_{42}$ to $An_{70} Ab_{30}$. The greenish pyroxene is pigeonite with a very low optic axial angle (less than 7°). Iron ore (titaniferous magnetite and ilmenite) is abundant in all the specimens both as skeletal crystals (11053) and as sharply defined prisms

0·1 mm. in length. Minor constituents are reddish-brown biotite (11056) and secondary carbonate, amphibole, and chlorite. In the absence of field data, the rocks are classified as medium- to fine-grained olivine-free basalts of sub-ophitic to intergranular texture.

The most likely source of the pebbles is the Auckland Islands, approximately 130 miles to the south of the Snares, this being the nearest area where basaltic rocks are known to occur (Speight and Finlayson, 1909, pp. 731–6). It should be noted, however, that the pyroxene in Auckland Island basalts, diabases, and dolerites is described as titaniferous augite and not pigeonite (*op. cit.*, p. 733). Other possible sources are the basaltic rocks on Campbell Island (Marshall, 1909, pp. 695–6) and Macquarie Island (Mawson, 1943, pp. 109–19). The few basaltic rocks described from the Antipodes Islands (Speight and Finlayson, 1909, p. 743), the more or less alkaline rocks from the Dunedin area (Benson, 1942, pp. 89–91), and the hornblende andesite rocks from Solander Island between Stewart Island and western Southland (Speight, 1909; Reed, 1951) differ markedly from the basalt pebbles at the Snares.

TABLE 1

ANALYSES OF GRANITE

—	A	B	C	D	E	F	G
SiO_2	73·83	72·00	73·56	73·08	77·28	73·01	73·16
Al_2O_3	13·91	12·96	11·19	11·98	11·12	14·95	13·74
Fe_2O_3	0·34	1·98	1·44	Nt. dt.	0·33	0·16	0·35
FeO	0·29	Nt. dt.	3·36	2·12	0·26	0·22	1·48
MgO	0·16	0·41	2·12	0·23	0·75	0·51	0·31
CaO	0·88	1·12	1·97	1·93	0·50	0·40	1·60
Na_2O	3·59	5·85	2·90	3·58	1·89	0·16	3·06
K_2O	4·44	4·06	3·26	6·57	6·95	8·24	5·03
H_2O+	1·30	0·20	0·30	0·29	0·52	2·20	0·46
H_2O-	0·61	Nt. dt.	0·14	0·23	0·13	0·10	0·39
TiO_2	0·07	1·56	0·21	..	0·02	0·02	0·23
P_2O_5	0·49	..	Tr.	0·01	0·35	0·19	0·17
MnO	0·10	0·30	0·19	Tr.	0·01	0·01	0·02
BaO	0·03	..	..	..	..	..	0·18
SrO	Nt. fd.	..	..	..	..	..	0·04
Cr_2O_3	Nt. fd.	..	..	..	..	..	..
ZrO_2	Nt. fd.	..	..	..	..	..	0·02
V_2O_3	Nt. fd.	..	..	..	..	..	..
S	0·04	..	..	..	..	..	..
Cl	Tr.	..	..	..	..	..	..
F	0·08	..	..	..	..	0·27	..
CO_2	Tr.	..	0·11	..	..	..	..
	100·16	100·44	100·35	100·02	100·11	100·44	100·24

A. Granite (11043), Snares Island. (This paper.) Analyst, F. T. Seelye. G = 2·56.

B. Unweathered granite, beach, Snares Island. Analyst, B. C. Aston (Aston, 1909, p. 769).

C. Granite, Auckland Islands. Analyst, A. M. Wright (Speight and Finlayson, 1909, p. 720).

D. Granite, Bounty Island. Analyst, R. Morgan (Speight and Finlayson, 1909, p. 739).

E. Granite, Stewart Island. Analyst, G. J. Williams (G. J. Williams, 1934, Table III, No. 1).

F. Muscovite-myrmekite granite, Stewart Island. Analyst, G. J. Williams (G. J. Williams, 1934, Table III, No. 2).

G. Granite inclusion in diorite, Green Islets. Analyst, F. T. Seelye (Park, 1926, p. 386).

TABLE 2

Normative Calculations of Granite (11043), Snares Island. A = Standard C.I.P.W. Weight Norm. B = Molecular Norm. (see Barth, 1948, p. 51)

—	A	B
Q	35·24	33·58
or	26·22	26·85
ab	30·36	33·00
an	0·84	0·90
C	2·89	3·24
hy	0·72	0·50
mt	0·48	0·48
il	0·14	0·10
ap	1·18	1·20
CaF_2	0·07	0·16

Symbol: I. 3(4). 1. 3.
(Alaskose)

TABLE 3

Granite (Snares Island) Showing Approximate Distribution of Chemical Constituent (Equivalent Mols. Per Cent) in the Modal Minerals Determined in Thin Sectio (*cf.* Barth, 1948, p. 55)

Si	Al	Fe+++	Fe++	Ti	Mg	Ca	Na	K	P	Mn	F	Modal Minerals
70·1	15·6	0·2	0·2	0·1	0·2	0·9	6·6	5·4	0·4	0·1	0·2	100·0
33·0	..	..	..	..	..	..	..	..	..	..	..	33·0 Q.
6·8	5·2	..	..	0·1	0·2	..	..	2·1	..	..	0·1	14·5 Muscovite
20·2	7·0	..	..	..	..	0·2	6·6	..	..	..	..	34·0 Plag.
..	..	..	..	..	..	0·7	..	..	0·4	..	0·1	1·2 ap.
..	..	0·2	0·1	..	..	..	..	..	..	..	..	0·3 or.
9·9	3·3	..	..	..	..	..	..	3·3	..	..	..	16·5 or.
0·2	0·1	..	0·1	..	..	..	..	..	..	0·1	..	0·5 garnet.

PART III

PEAT SAMPLES

By W. F. Harris, Botany Division, D.S.I.R.

SUMMARY

A series of thirteen peat samples was collected by C. A. Fleming from a single exposure on the northern part of the main Snares Island. Examination reveals a steady increase of grass pollen in relation to the amount of forest pollen. Other pollens, mainly Umbelliferae and Araliaceae, together with fern spores, attain their greatest relative importance in the middle stage. Pollen deposition appears to record the local gradual replacement of *Olearia* forest, the succession being *forest – herb meadow – tussock grassland* and the respective dominants *Olearia, Stilbocarpa – Anisotome,* and species of *Poa.*

The pollen data are of interest as a sample profile from a station within the subantarctic climate belt, differing from mainland stations in being near the southern tree limit, and at a distance from the anemophilous beech and conifer forests. Also, because peat soils are zonal (climatic), difficulties of statistical representation of bog- and non-bog pollens do not arise. Further borings may confirm that the peat is a young deposit. The average depth is about 8 ft, but the high pollen-content suggests slow accumulation. The concentration of pollen on an average slide is 11,800 grains per square centimetre. Wind-borne pollens from the mainland do not amount to 0·5 per cent of the total pollen in any sample. Pollen of Umbelliferae, presumably *Anisotome acutifolia,* increases to 43 per cent of the non-grass pollen in Sample 6. This species is now practically extinct and was found in one locality only in 1890. The pollen counts, in comparison with the present vegetation of the island, show the need for a well-planned study when the aim is to interpret regional climate from pollen statistics.

LOCALITY AND SAMPLING

Situation, Climate, and Vegetation

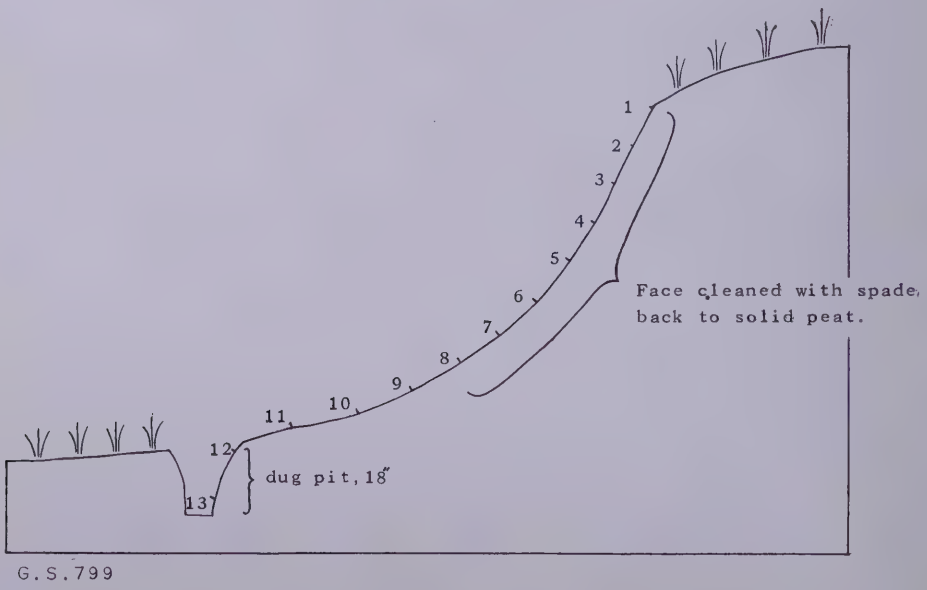
The Snares group comprises two large and several small granite islets situated in latitude 48° S., 65 miles from South Cape, Stewart Island. The climate is cool, uniform, and humid, with much cloud and wind. The largest island, irregular in shape and about a mile and a half in its greatest diameter, bears, over the greater portion, a vegetal covering of low forest and scrub, with a marginal tussock area between the forest and the steep cliffs. The flora is a small one, consisting of three woody species, three ferns, and a few herbs, grasses, and sedges. Only a few of the twenty-three recorded species are common. More detailed descriptions are to be found in the volumes of *The Subantarctic Islands of New Zealand* (1909) and in papers by T. Kirk (1891) and F. R. Chapman (1891).

Samples

The samples were taken at vertical intervals of approximately 1 ft, from a face cleaned back to the solid peat with a spade. The locality is at an altitude of approximately 250 ft above sea-level, just south of the large sink-hole in the narrow isthmus which almost divides the northern part of the main Snares Island.

The surrounding vegetation consists of *Poa foliosa* meadow, with *Poa astoni* and *Hebe elliptica* nearby. Sample No. 1 was taken from the roots of *Poa*, the others in downward succession. The lower 10 ft of peat was waxy with roughly conchoidal fracture and irregular joints. The lowest sample (No. 13) was perhaps 2 ft above the rock, which could not be reached by digging but which crops out at the surface nearby (Fig. 16).

Fig. 16—From a field sketch by C. A. Fleming, showing method of sampling the profile.



RESULTS OF POLLEN COUNTS

Indigenous Pollens

Recent pollen of several subantarctic species was kindly supplied by W. B. Brockie, Otari Plant Museum, from his Campbell Island material. Some of the Snares species, however, are still not represented in the reference slide collection.

Preliminary counts were made to ascertain the proportions of grass, herb, fern, and forest spores, and the results are shown in the graph, Fig. 17.

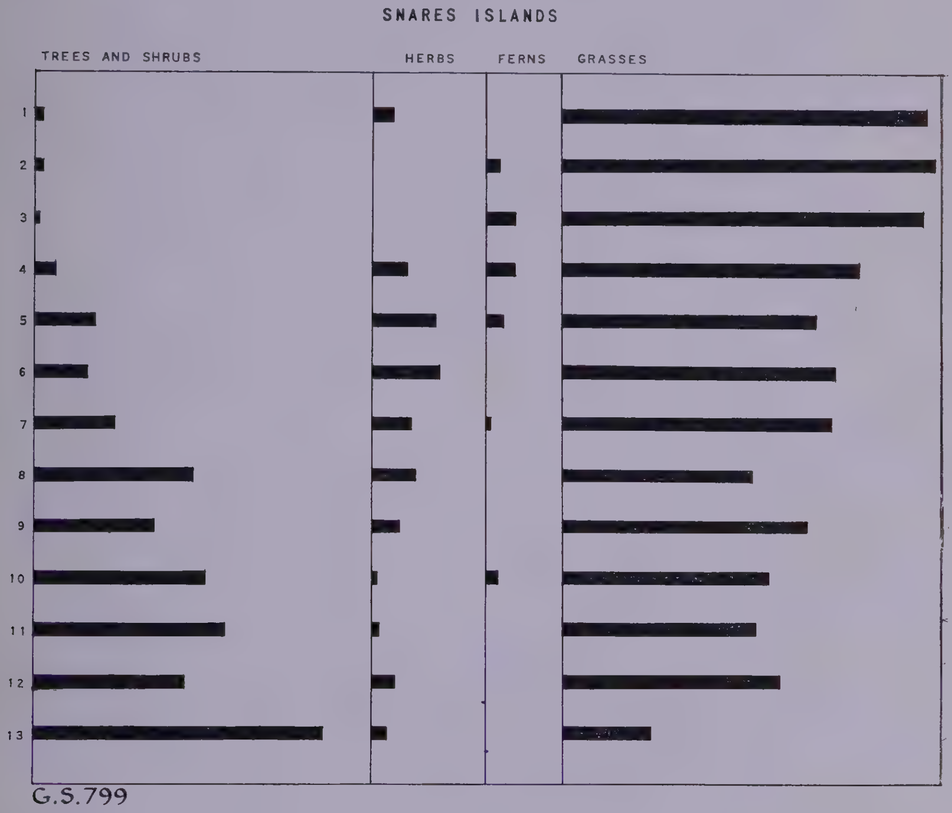


Fig. 17—Graph showing relation of arboreal pollen to that of herbs, ferns, and grasses, expressed as percentages of the total pollen.

A hundred non-grass pollens were then counted on each slide (in some cases two hundred) to get the percentages without the influence of variations in grass pollen concentration. It is noteworthy that the shape of the *Olearia* curve (Fig. 18) is very similar to the one obtained from total pollen. In Samples 2, 3, and 4, where *Olearia* pollen occurs in greatly diminished quantities, fern spores are increasingly important.

In these sharp fluctuations the curves reflect the influence of local shedding. Forest pollens from beyond the bog area, as in mainland deposits, show the smoothing or averaging effect of atmospheric diffusion.

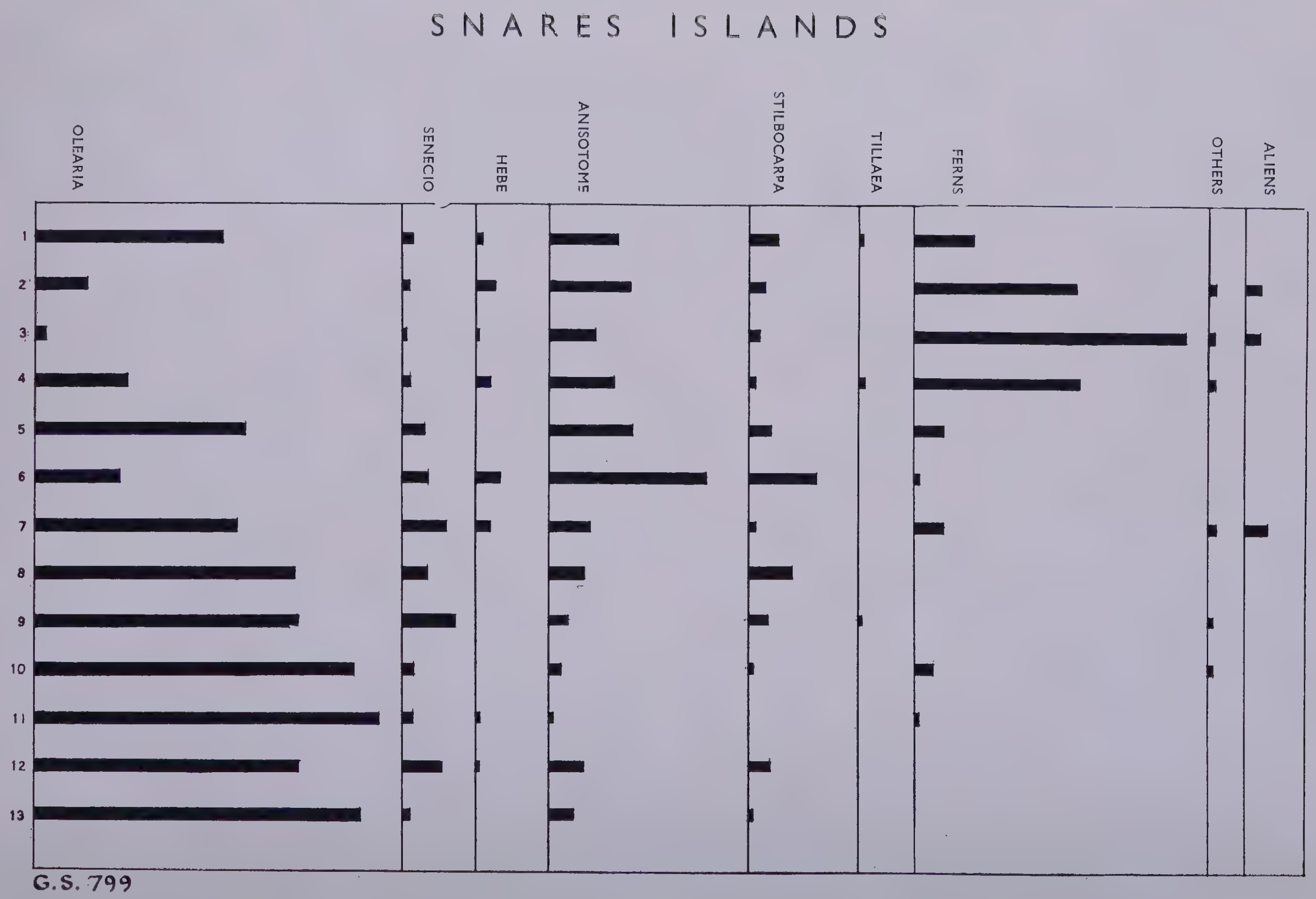


Fig. 18—Graph showing percentages of pollen types other than grass.

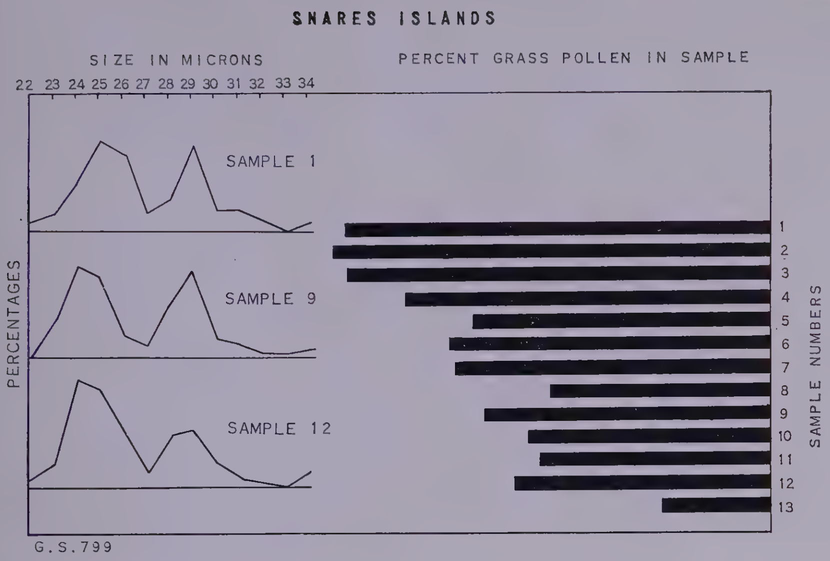


Fig. 19—Graph showing size-frequency in 100 grass pollens at three levels in the profile, and percentage grass pollen in the samples.

One hundred grass pollens were measured at three levels. A trimodal curve resulted (Fig. 19), but there was no variation in the total size-range at the three levels. Curves from reference slides of the grass species are not available for comparison. The results, however, discount the idea that other grasses, such as species of *Danthonia,* might have been present during the earlier part of the deposition period.

Alien Pollens

The presence of pollens of non-indigenous species might occur through contamination or as the result of wind carriage. Such alien pollens in no case amount to even 0·5 per cent of the total pollen. On a slide estimated to contain 100,400 pollens, only two alien pollens (rimu) were seen when half the slide was examined under low power. Pollens of the podocarp type (totara and miro) were found on some slides, also of species of *Nothofagus* (including in one instance *N. menziesii*), but in no case in sufficient concentration to have any statistical value. In the uppermost sample, pollen of the thistle type (*Carduus – Cirsium*) was noted, possibly from an adventitious flora introduced by the sealers.

Identifications

The fern spores are of the bi-lateral type and the perispore is not preserved. The remaining characters—size, shape, and thickness of wall—are variable and overlap to some extent.

Pollens of the following indigenous plants were recognized: *Colobanthus muscoides* (few), *Tillaea moschata* (few), *Callitriche antarctica* (few), *Anisotome acutifolia* (common), *Stilbocarpa robusta* (common), *Olearia lyallii* (abundant), *Senecio stewartiae* (common), *Hebe elliptica* (common). Sedges, grasses, and ferns could not be referred to species. The following species recorded from the islands are not represented in the pollen counts: *Cardamine depressa, Lepidium oleraceum, Myosotis albida, Juncus bufonius.*

DISCUSSION

From the information available, peat-formation appears to be climatic, and it is of interest that such a peat can support a low forest vegetation. Peat is retentive of moisture, and, as a result of poor drainage, would tend to form a dome-shaped mound. Deficient aeration would account for the continued accumulation of plant debris, but the availability of mineral salts in solution would become progressively less. As the depth of peat increased, a succession would be expected from forest to dwarf sedges and herbs, and sooner or later to moss. When peat-formation is due to topography, forest may be maintained at the margin both by root access to the substratum and by the influence of incoming water. The marginal succession to grass on many parts of the Snares suggests that, as a result of drainage from the interior, the margin is maintained in too wet a condition for forest.

Since the pollen counts reveal no changes in the vegetation of the islands such as were reported by Cranwell and von Post from the Otago bogs, it may be suggested that peat-formation began under the cooler conditions of the third postglacial period and that the deposit is a young one—less than 2,500 years old. If the peat formation is climatic, as the evidence suggests, and not topogenous, it seems possible that the peat has been maintained at a relatively high level of fertility by the animal population.

A similar change to grass in the forest margin in the fiord region has been reported by J. T. Holloway (letter, 23 February 1950), who adds the comment that, if the evident changes are due to climatic factors, he would suggest the possibility of the peats being even younger than 2,000 years, say 1,000 to 700 years old.

REFERENCES

Allan, R. S. (1925): Preliminary Account of the Geology of Chatham Islands. *N.Z. J. Sci. Tech. 7* : 290–4.

Armstrong, H. (1869): The Cruise of the Brig "Amherst". *N.Z. Govt. Gazette. Province of Southland. 6 (8)*: 51–8.

Aston, B. C. (1909): The Soils and Soil-formers of the Subantarctic Islands. "The Subantarctic Islands of New Zealand." Vol. 2, pp. 745–77.

Barth, T. F. W. (1948): Oxygen in Rocks: A Basis for Petrographic Calculations. *J. Geol. 56* : 50–60.

Benson, W. N. (1934): The Geology of the Region about Preservation and Chalky Inlets, South-west Fiordland, New Zealand. Part 1. *Trans. N.Z. Inst. 63* : 393–432.

——— (1935): Some Land Forms in Southern New Zealand. *Aust. Geog. 2 (7)* : 3–22.

——— (1941): The Basic Igneous Rocks of Eastern Otago and their Tectonic Environment. Part 1. *Trans. Roy. Soc. N.Z. 71* : 208–22.

——— (1942): The Basic Igneous Rocks of Eastern Otago and their Tectonic Environment. Part 2. *Ibid. 72* : 85–110.

Benson, W. N., and Bartrum, J. A. (1935): The Geology of the Region about Preservation and Chalky Inlets, South-west Fiordland, New Zealand, Part 3. *Ibid. 65* : 108–52.

Benson, W. N., Bartrum, J. A., and King, L. C. (1934): The Geology of The Region about Preservation and Chalky Inlets, South-west Fiordland, New Zealand. Part 2. *Ibid. 64* : 51–86.

Bertram, G. C. L. (1940): The Biology of the Weddell and Crabeater Seals, with a Study of the Comparative Behaviour of the Pinnipedia. *Brit. Grahamsland Exped. 1934–37, Sci. Rep. 1 (1)* : 1–139.

Chapman, F. R. (1891): The Outlying Islands South of New Zealand. *Trans. N.Z. Inst. 23* : 491–522.

Cockayne, L. (1909): Ecology of the Plant Formations. "The Subantarctic Islands of New Zealand." Vol. 1, p. 207.

Cranwell, L. M., and Von Post, L. (1936): Post-Pleistocene Pollen Diagrams from the Southern Hemisphere. *Geogr. Ann Stockh, 3–4* : 308–47.

Emery, K. O. (1941): Transportation of Rock Particles by Sea-mammals. *J. sediment. Petrol. 11 (2)* : 92–3.

Falla, R. A. (1948): The Outlying Islands of New Zealand. *N.Z. Geographer 4 (2)* : 127–54.

Fleming, C. A. (1951): Sea-lions as Geological Agents. *Ibid. 21 (1)* : 22–5.

Gage, M. (1949): The Conditions of Deposition of Greymouth Coal. *Trans. Roy. Soc. N.Z. 77* : 338–45.

Hamilton, J. E. (1934): The Southern Sea Lion. *Discovery Rep. 8* : 239–64.

Hector, J. (1870): Notes on the Geology of the Outlying Islands of New Zealand, with Extracts from Official Reports. *Trans. N.Z. Ins. 2* : 176–86.

——— (1896): Note on the Geology of the Outlying Islands of New Zealand. *Ibid. 28* : 736–8

Henderson, J. (1924): The Post-Tertiary History of New Zealand. *Ibid. 55* : 580–99.

Kirk, T. (1891): On the Botany of the Snares. *Ibid. 23* : 426–31.

MACPHERSON, E. O. (1946): An Outline of Late Cretaceous and Tertiary Diastrophism in New Zealand. *N.Z. Dep. Sci. Industr. Res. Geol. Mem. 6.* 32 pp.

MARSHALL, P. (1909) (assisted by R. Browne): The Geology of Campbell Island and The Snares. "The Subantarctic Islands of New Zealand." Vol. 2, pp. 680–704.

MAWSON, D. (1943): Macquarie Island, its Geography and Geology. *Rep. Aust. Antarct. Exped. 1914–19, Ser. A, Vol. 5.*

MURPHY, GRACE E. B. (1948): A Naturalist's Wife in the Sub-Antarctic. *Nat. Hist. N.Y. 57* : 344–8, 412–6, 468–74.

MURPHY, R. C. (1948): A New Zealand Expedition of the American Museum of Natural History. *Science 108* : 463–4.

NIKITIN, W. (1936): "Die Federow Methode." Borntraeger, Berlin.

OLIVER, R. L. (1950): Preliminary Report on the Geology of Campbell Island. *N.Z. Dep. Sci. Industr. Res. Cape Exped. Bull. 3* : 7–44.

PARK, J. (1926); Granite Enclosures in a Quartz-biotite-diorite at Green Islets, Southland. *Trans. N.Z. Inst. 56* : 384–6.

REED, J. J. (1948): Igneous Rocks. In "The Outline of the Geology of New Zealand". N.Z. Geological Survey, Wellington.

——— (1951): Hornblende Andesite Rocks from Solander Island. *Trans. Roy. Soc. N.Z. 79* : 119–25.

RICHDALE, L. E. (1948): Wild Life on an Island Outpost. *Expedition to the Snares Islands (1947–48). No. 8.* Otago Daily Times, Dunedin.

SHEPARD, F. (1948). "Submarine Geology." Harper, New York.

SPEIGHT, R. (1909): On a Horneblende-andesite from Solander Islands. *Trans. N.Z. Inst. 41* : 52–3.

SPEIGHT, R., and FINLAYSON, A. M. (1909): Physiography and Geology of the Auckland, Bounty, and Antipodes Islands. "The Subantarctic Islands of New Zealand." Vol. 2, pp. 705–44.

TURNER, F. J. (1947): Determination of Plagioclase with the Four-axis Universal Stage. *Amer. Min. 32* : 389–410.

TURNER, W. (1887); Report on the Seals Collected During the Voyage of H.M.S. "Challenger" in the Years 1873–76. *Challenger Rep. 68* : 1–240.

WELLMAN, H. W. (1949): Palaeozoic. In "The Outline of the Geology of New Zealand." N.Z. Geological Survey, Wellington.

WILLETT, R. W. (1951): The New Zealand Pleistocene Snow Line, Climatic Conditions, and Suggested Biological Effects. *N.Z. J. Sci. Tech. B32 (1)* : 18–48.

WILLIAMS, G. J. (1934a): The Auriferous Tin Placers of Stewart Island, New Zealand. *Ibid. 15* : 344–57.

——— (1934b): A Granite-schist Contact in Stewart Island, New Zealand. *Quart. J. Geol. Soc. 90* : 322–53.

——— (1936): The Geomorphology of Stewart Island, New Zealand. *Geog. J. 87(4)* : 328–37.

WILSON, E. A. (1907): Mammalia (Whales and Seals). *Nat. Antarct. Exped. 1901–4, Nat. Hist. 2* : 1–66.

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